Lithium-Ion Verification Test Program - Applications

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Abstract

In order to assess the capabilities of current aerospace lithium-ion cells to perform long-term NASA missions, low-earth-orbit (LEO) testing to evaluate long-term cycle life was initiated. A flexible program was developed at NASA Glenn Research Center to enable assessment of technology developments as they occur as well as provide information about different cell vendors and cell designs. Following extensive characterization testing, cells are tested using LEO charge and discharge profiles under ten different combinations of test conditions that were statistically chosen to determine the effects of depth-of-discharge, temperature, and end-of-charge voltage on LEO cycle life. Four cells from each vendor are tested at each specific combination of conditions. Conditions included in the test matrix are depth-of-discharges of 20%, 30, 35%, and 40%; temperatures of 20, 30, and 40 °C; and end-of-charge voltages of 3.85 V, 3.95 V, and 4.05 V. Cells are randomly assigned to packs and packs are randomly assigned to test conditions. The capacity of the cells to 3.0 V at the conditions of the test is being periodically measured. The results of this testing will be used to model cell performance and degradation as a function of test operating conditions. Cells are being evaluated in 4-cell series strings with charge voltage limits being applied to individual cells by charge control units designed and built at NASA Glenn Research Center. Testing is being performed at the Naval Surface Warfare Center/Crane Division in Crane, IN. Testing was initiated in September 2004 with 40 Ah cells from Saft and 30 Ah cells from Lithion. The test program is being expanded with the addition of cells from MSA and the addition of small cell modules is being considered. Preliminary results showing voltage, temperature, usable capacity per unit mass, and voltage dispersion as their changes over time for the cells at 20 °C is presented.

Lithium-Ion Verification Test Program

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at Lewis Field

Li-Ion Verification Test Program

- Need for technology verification for aerospace applications
- Structure flexible program that will allow assessment of current technology capabilities
- Provide information about various vendors
- Provide for assessment of technology developments
- Developed statistical DOE to interpret relationships in data and to address program test goals and resource limitations
- Data will be used to develop a model to predict life of cells as a function of DOD, temperature, and EOCV

Li-Ion Verification Test Program

- Purchased 40 cells from two vendors
  - 40 Ah SAFT (10 additional cells at MSFC)
    - G4 chemistry space cells (HE54245)- Lithiated Nickel Oxide based cathode with Graphite based anode using carbonate solvents + $LiPF_6$ electrolyte
  - 30 Ah Lithion (10 additional cell at MSFC)
    - INCP 95/28/154 - Lithiated Nickel Cobalt Oxide cathode with Graphite anode using EC:DMC:DEC electrolyte
- Will be receiving 40 cells from MSA (50 Ah) at the end of the year
- Small cell concept under consideration

Li-Ion Verification Test Program

- **Test Variables**
  - Vendor: SAFT, Lithion, MSA
  - Depth of Discharge: 20, 30, 40% for Yardney & MSA; 20, 30, 35% for Saft
  - Test Temperature: 10°C, 20°C, 30°C
  - End of Charge Voltage: 3.85V, 3.95V, 4.05V
- Cell test conditions based on average actual discharge capacity from 4.1 V to 3.0 V at C/2 and 20°C

Li-Ion Verification Test Program

- Individual cells electrically assembled into 4 cell packs at ten test conditions
- Cells randomly assigned to packs
- Packs randomly assigned to conditions
- Average Capacity
  - Saft: 45.9 Ah
  - Lithion: 32.7 Ah
- LEO testing at 20°C started September, 2004 at NSWC/Crane, rest of testing will start in November, 2004

Li-Ion Test Charge Control

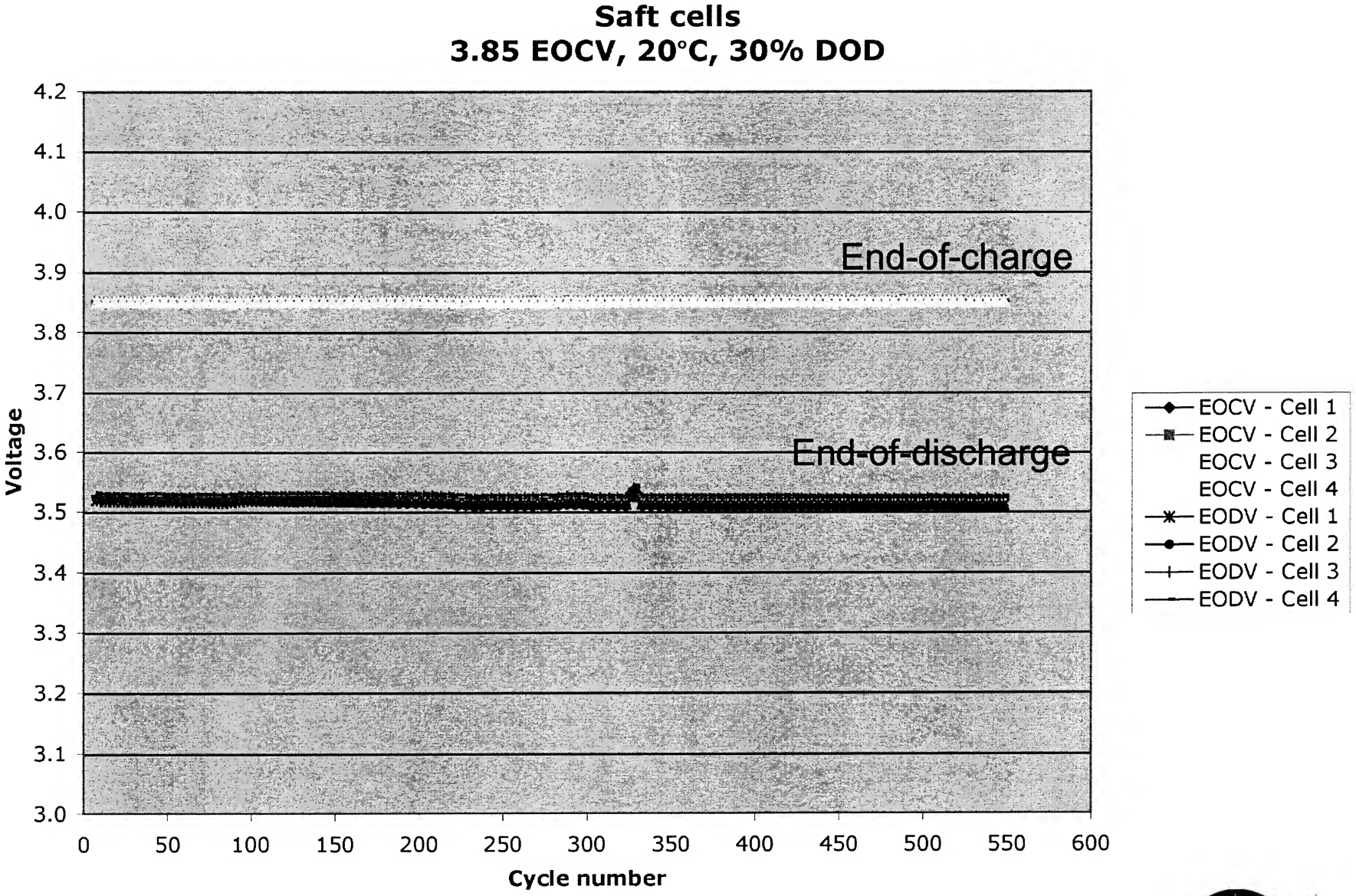
- Charge control circuitry – addresses cells individually
  - Clamp individual cell voltage as each cell reaches limit with cell charge control circuit that bypasses excess current and allows current to taper
  - When all cells reach limit, taper pack current by smallest cell bypass current
  - Continue for the time allotted for charge
- Charge control hardware developed and built at GRC
- Charge control software developed and implemented by NSWC/Crane to minimize bypassed current and heat generation

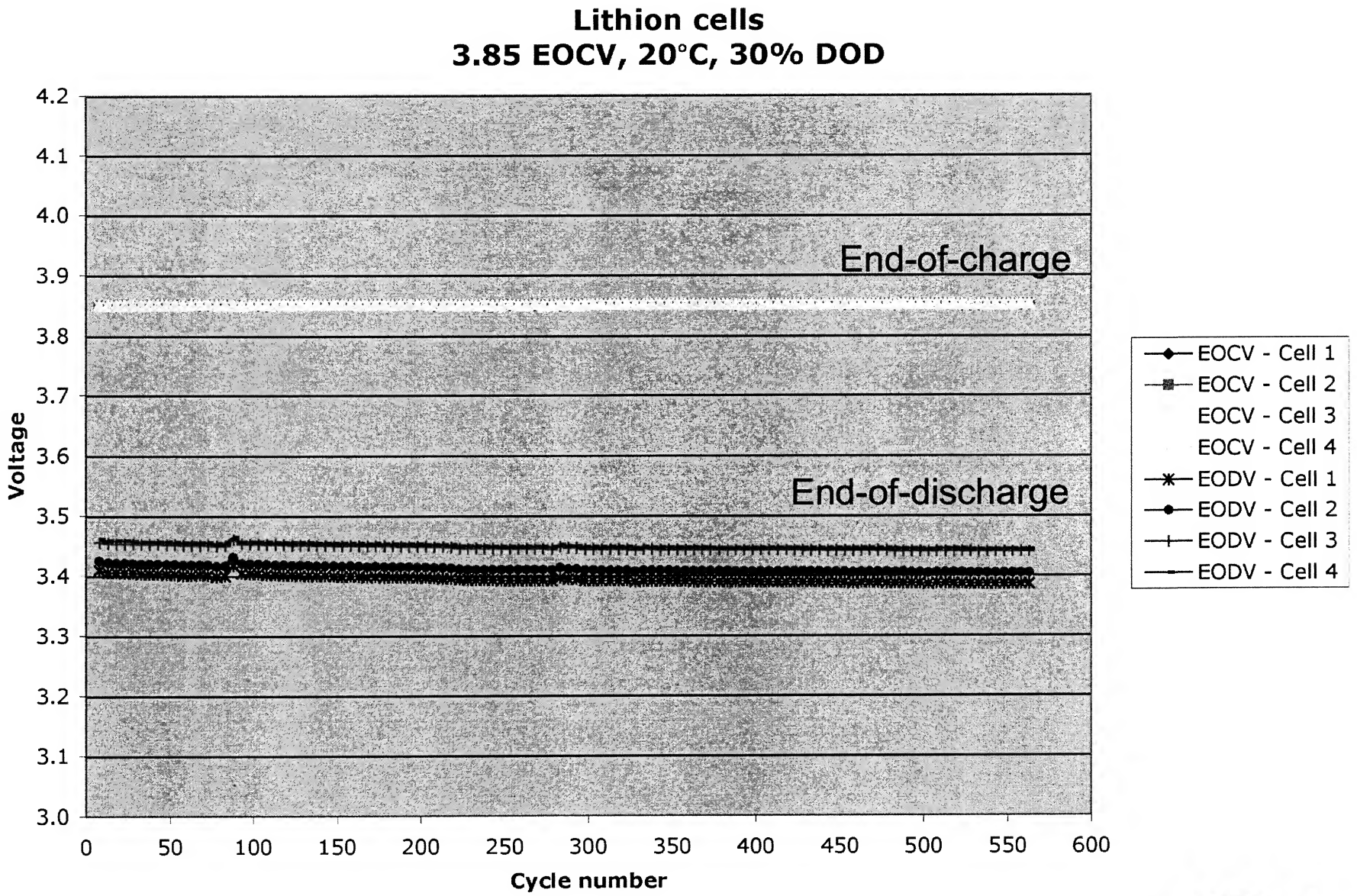
Li-Ion Cell Test Matrix

Temp(°C)	Voltage	DoD	Lab
30	4.05	20	GRC
30	3.85	20	GRC
10	3.85	20	GRC
30	3.95	30	GRC
20	3.95	20	GRC
10	3.85	40[1]/35[2]	GRC
20	3.85	30	GRC
30	3.85	40[1]/35[2]	GRC
20	4.05	40[1]/35[2]	GRC
10	4.05	30	GRC
30	4.05	40[1]/35[2]	MSFC
10	4.05	20	MSFC

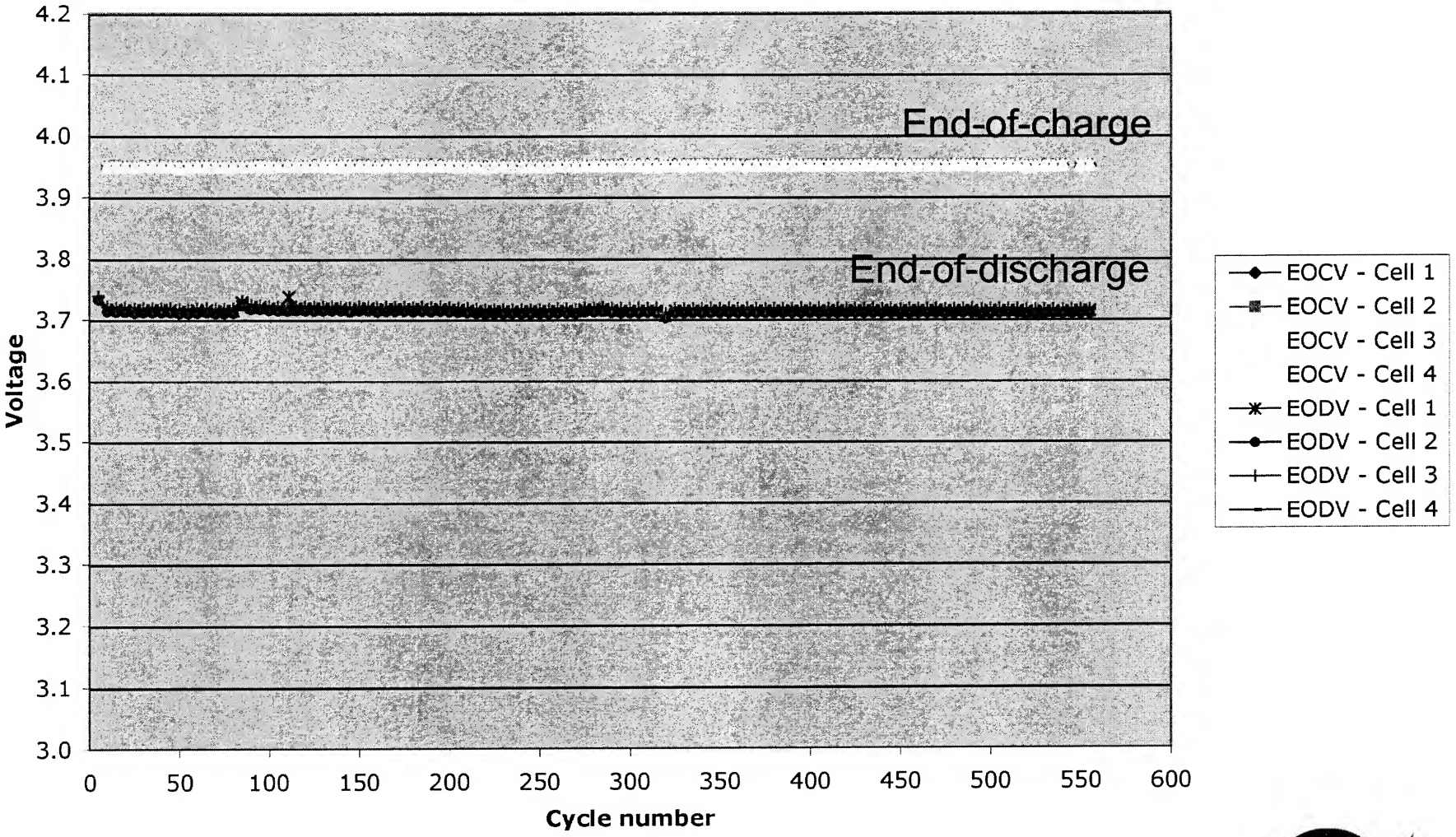
1 - Lithion, MSA

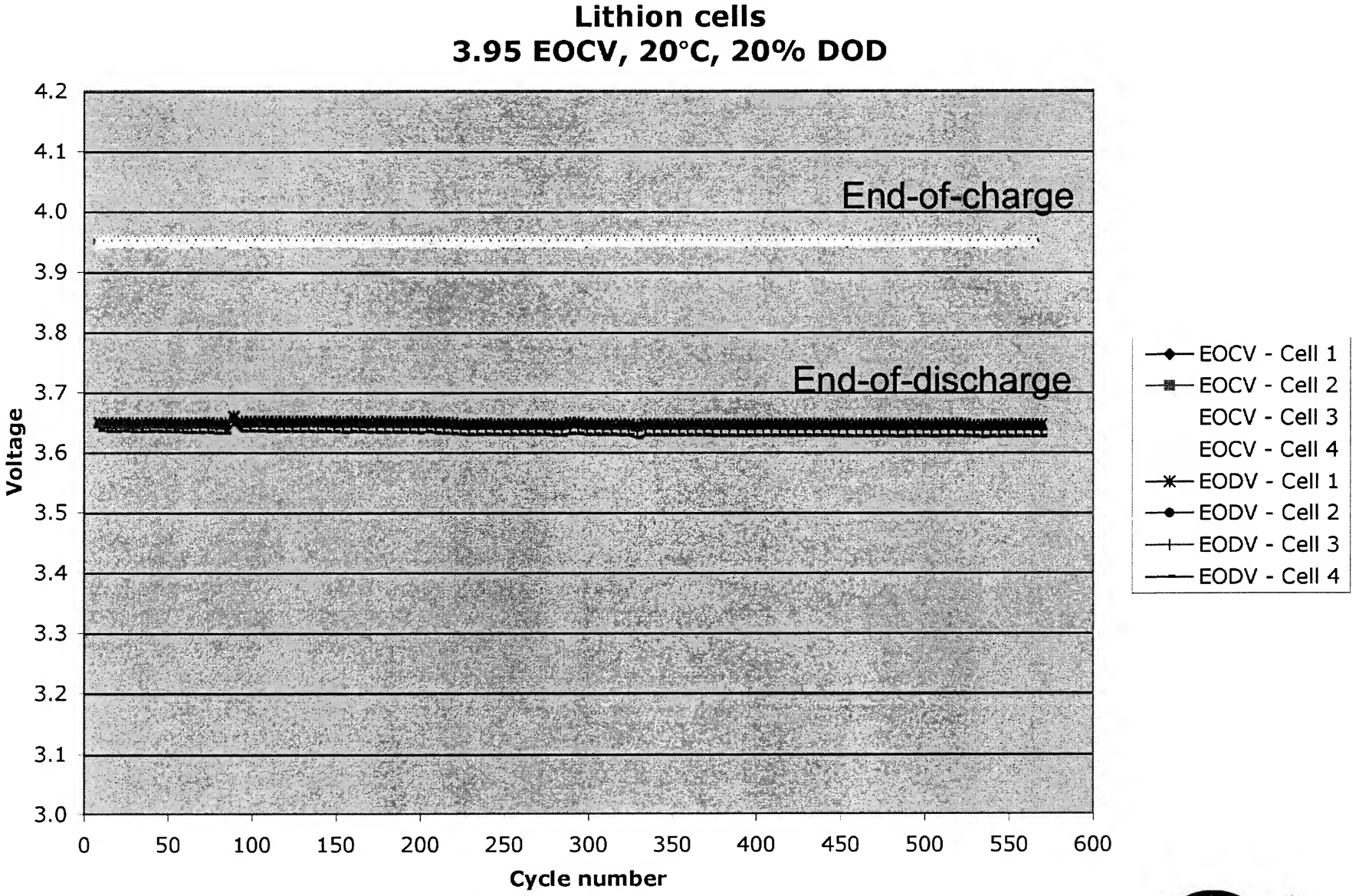
2 - Saft

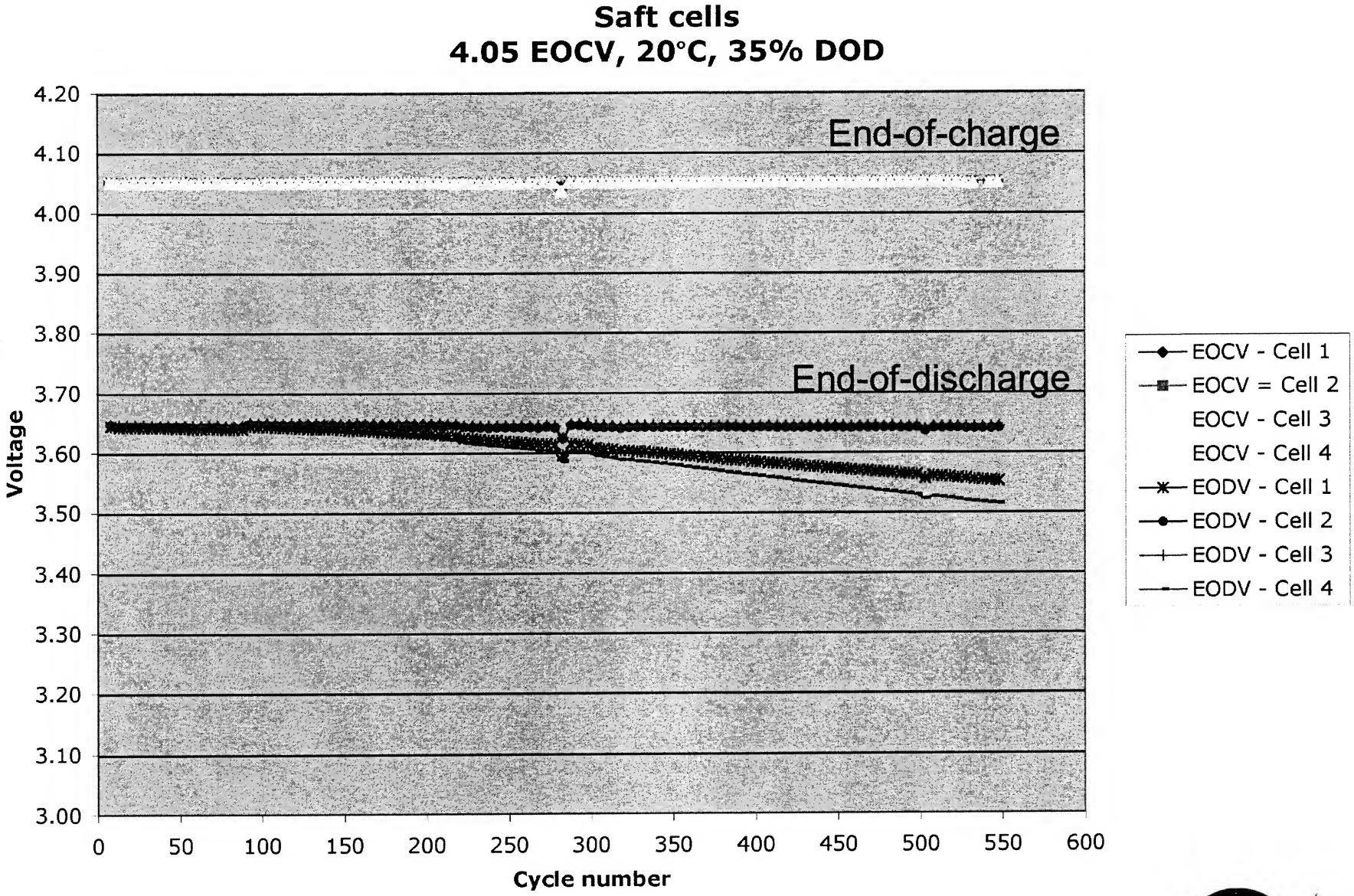

Saft cells
3.85 EOCV, 20°C, 30% DOD
End-of-charge
End-of-discharge
Voltage
Cycle number
4.2
4.1
4.0
3.9
3.8
3.7
3.6
3.5
3.4
3.3
3.2
3.1
3.0
0
50
100
150
200
250
300
350
400
450
500
550
600
EOCV - Cell 1
EOCV - Cell 2
EOCV - Cell 3
EOCV - Cell 4
EODV - Cell 1
EODV - Cell 2
EODV - Cell 3
EODV - Cell 4

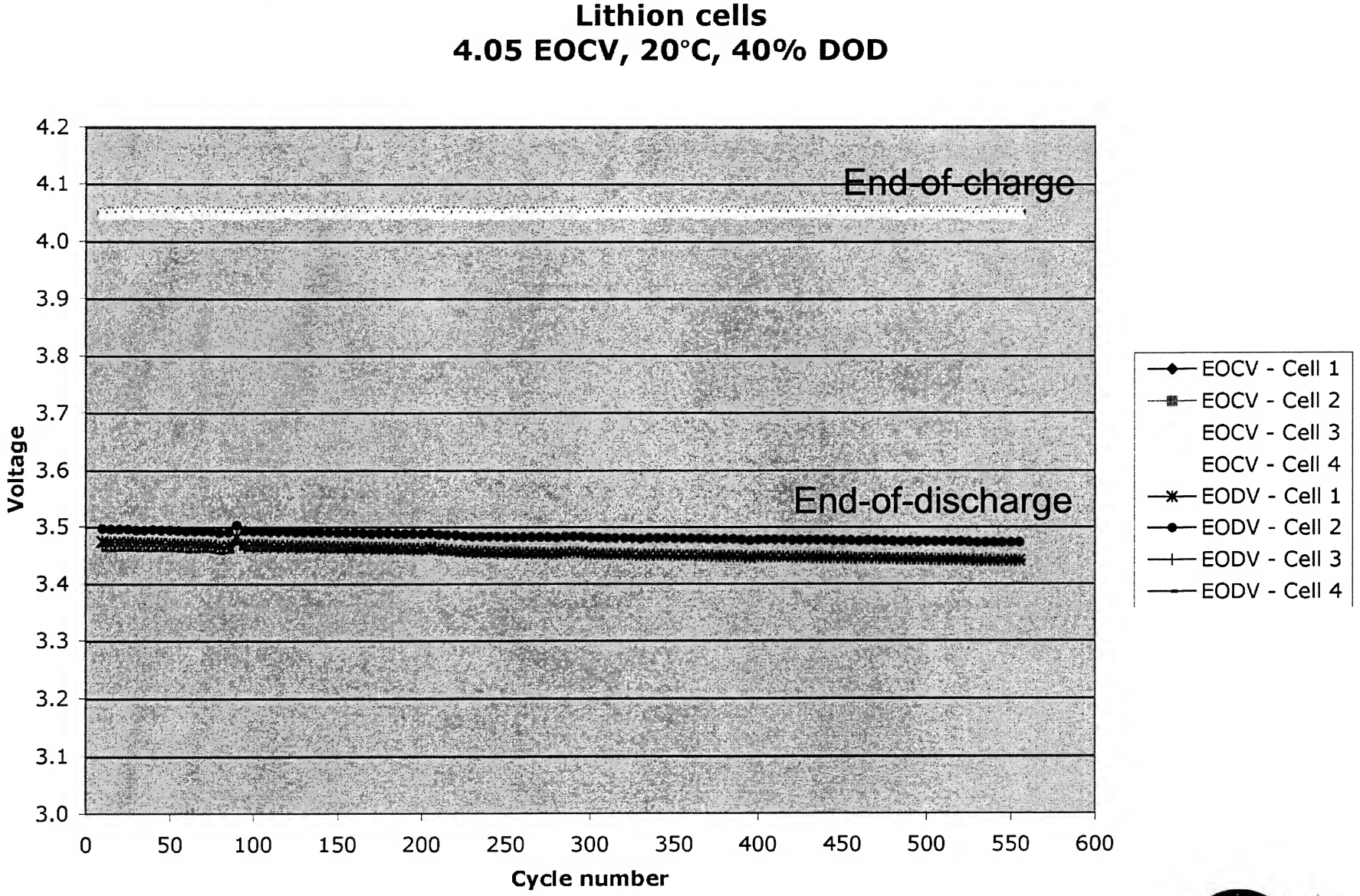

Lithion cells
3.85 EOCV, 20°C, 30% DOD
End-of-charge
End-of-discharge
Voltage
Cycle number
4.2
4.1
4.0
3.9
3.8
3.7
3.6
3.5
3.4
3.3
3.2
3.1
3.0
0
50
100
150
200
250
300
350
400
450
500
550
600
EOCV - Cell 1
EOCV - Cell 2
EOCV - Cell 3
EOCV - Cell 4
EODV - Cell 1
EODV - Cell 2
EODV - Cell 3
EODV - Cell 4

Saft cells
3.95 EOCV, 20°C, 20% DOD

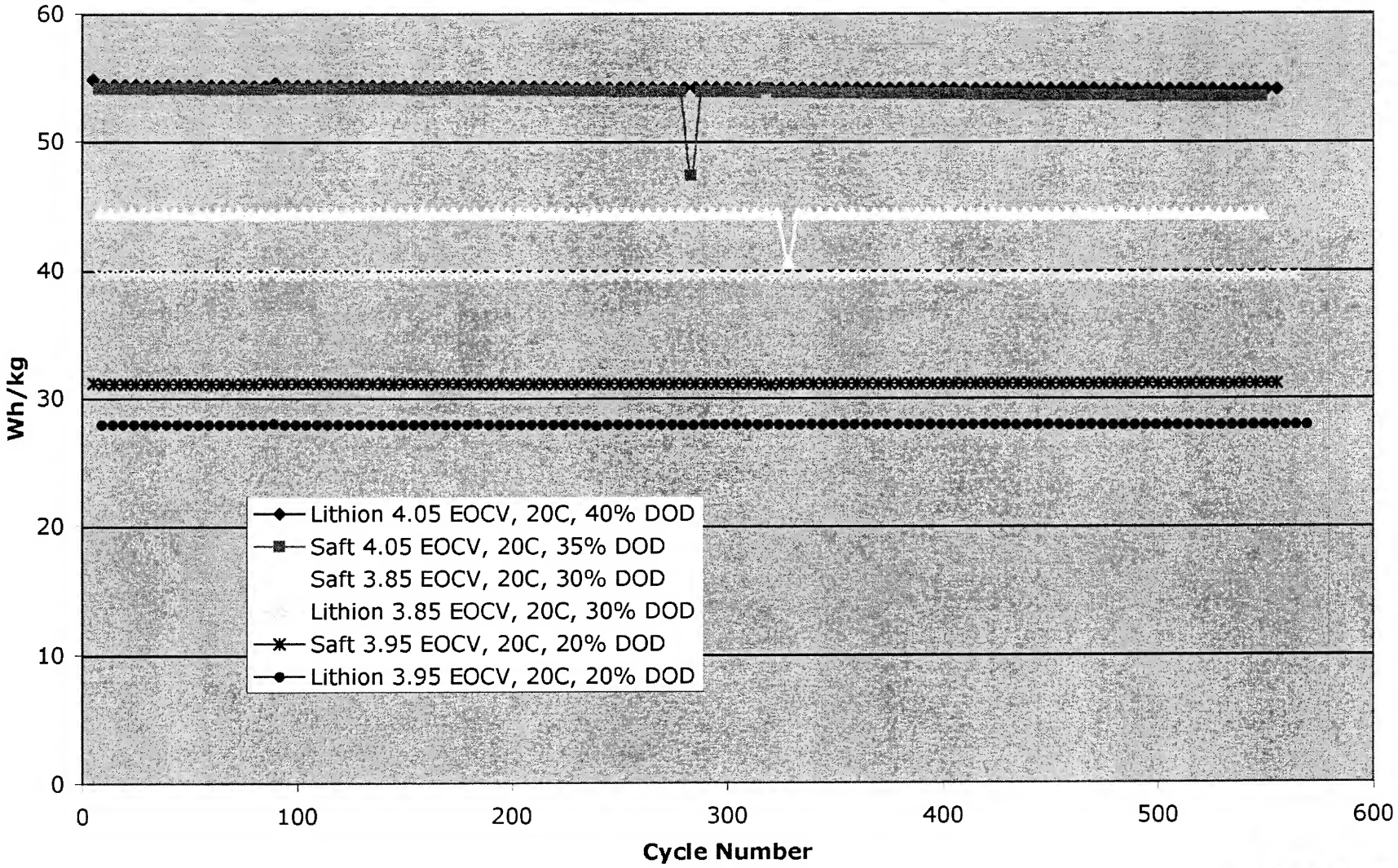



Lithion cells
3.95 EOCV, 20°C, 20% DOD
End-of-charge
End-of-discharge
Voltage
Cycle number
4.2
4.1
4.0
3.9
3.8
3.7
3.6
3.5
3.4
3.3
3.2
3.1
3.0
0
50
100
150
200
250
300
350
400
450
500
550
600
EOCV - Cell 1
EOCV - Cell 2
EOCV - Cell 3
EOCV - Cell 4
EODV - Cell 1
EODV - Cell 2
EODV - Cell 3
EODV - Cell 4

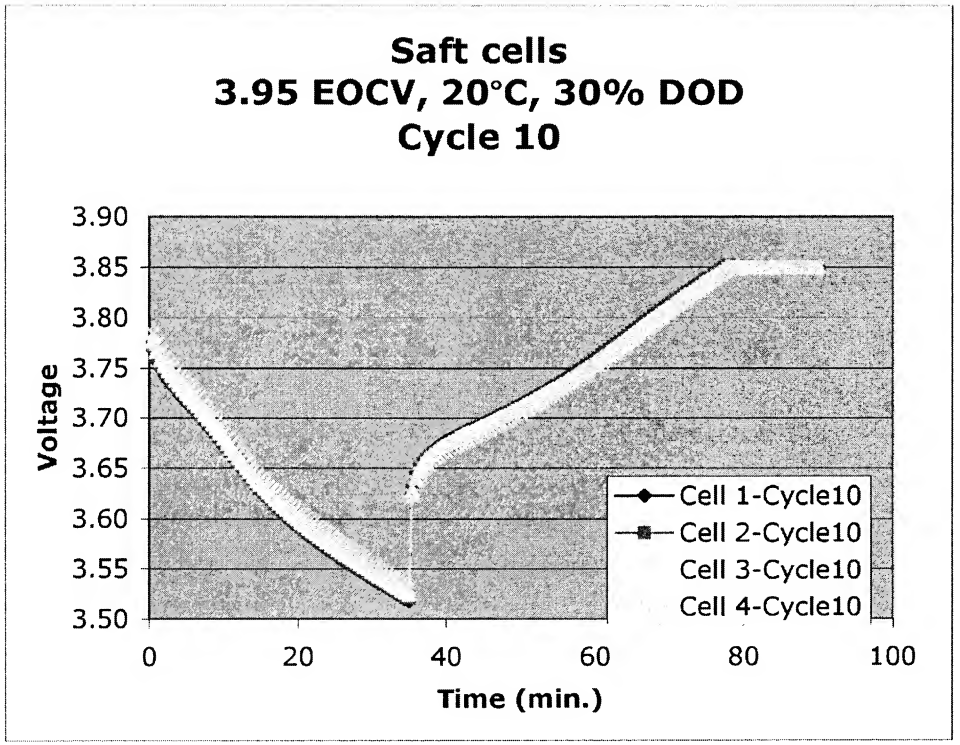

Saft cells
4.05 EOCV, 20°C, 35% DOD
End-of-charge
End-of-discharge
Voltage
4.20
4.10
4.00
3.90
3.80
3.70
3.60
3.50
3.40
3.30
3.20
3.10
3.00
0
50
100
150
200
250
300
350
400
450
500
550
600
Cycle number
EOCV - Cell 1
EOCV = Cell 2
EOCV - Cell 3
EOCV - Cell 4
EODV - Cell 1
EODV - Cell 2
EODV - Cell 3
EODV - Cell 4

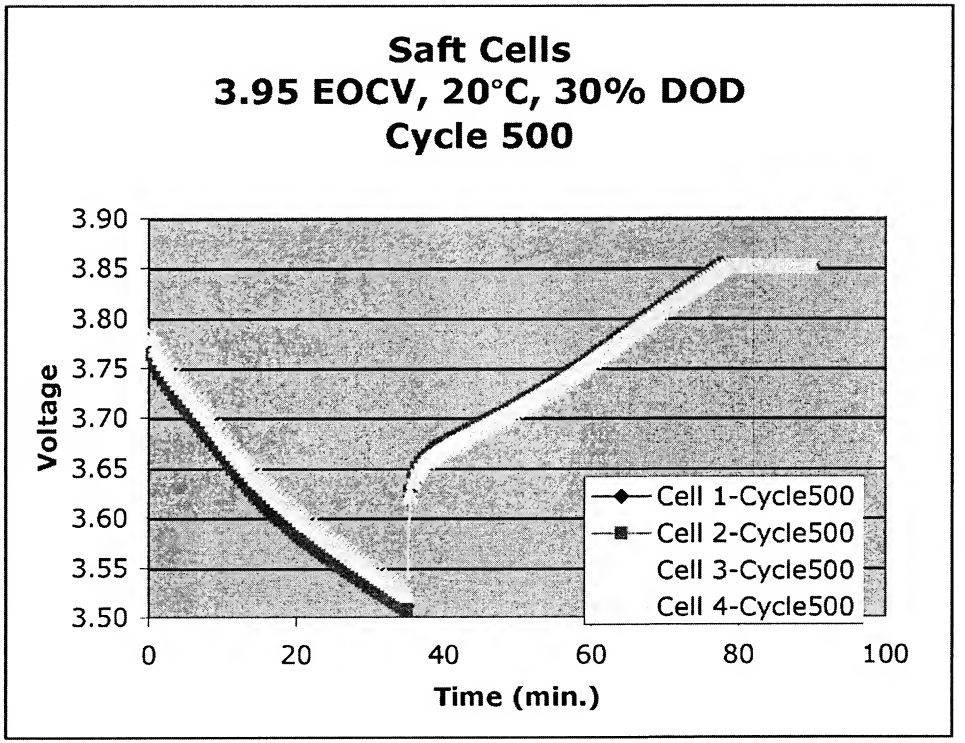

Lithion cells
4.05 EOCV, 20°C, 40% DOD
End-of-charge
End-of-discharge
Voltage
Cycle number
4.2
4.1
4.0
3.9
3.8
3.7
3.6
3.5
3.4
3.3
3.2
3.1
3.0
0
50
100
150
200
250
300
350
400
450
500
550
600
EOCV - Cell 1
EOCV - Cell 2
EOCV - Cell 3
EOCV - Cell 4
EODV - Cell 1
EODV - Cell 2
EODV - Cell 3
EODV - Cell 4

Average Cell Energy Density Delivered

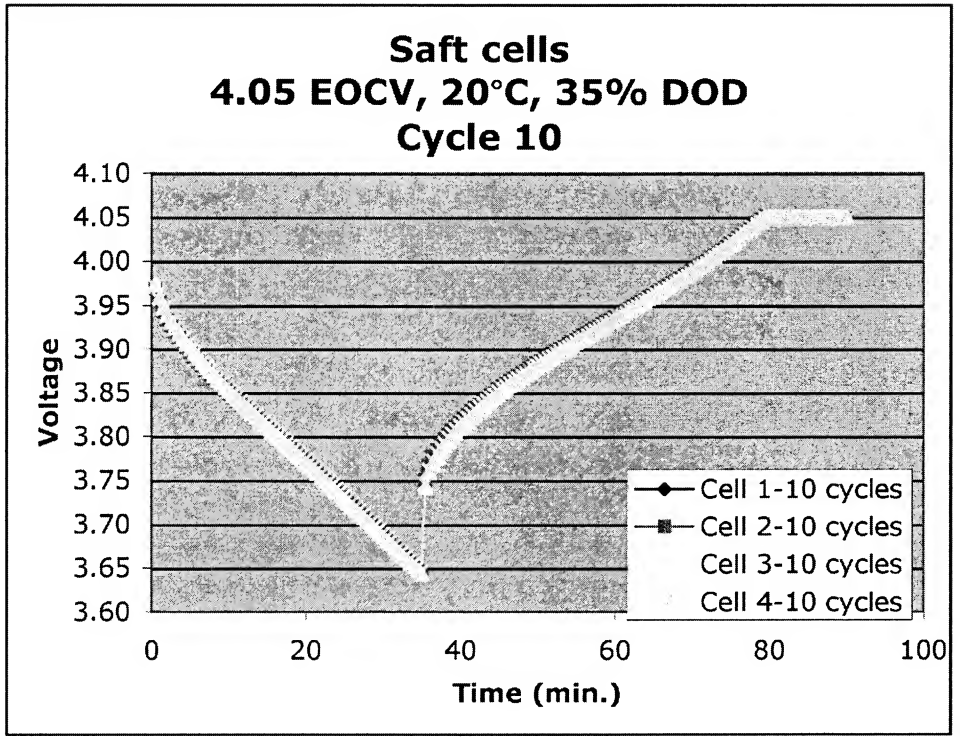


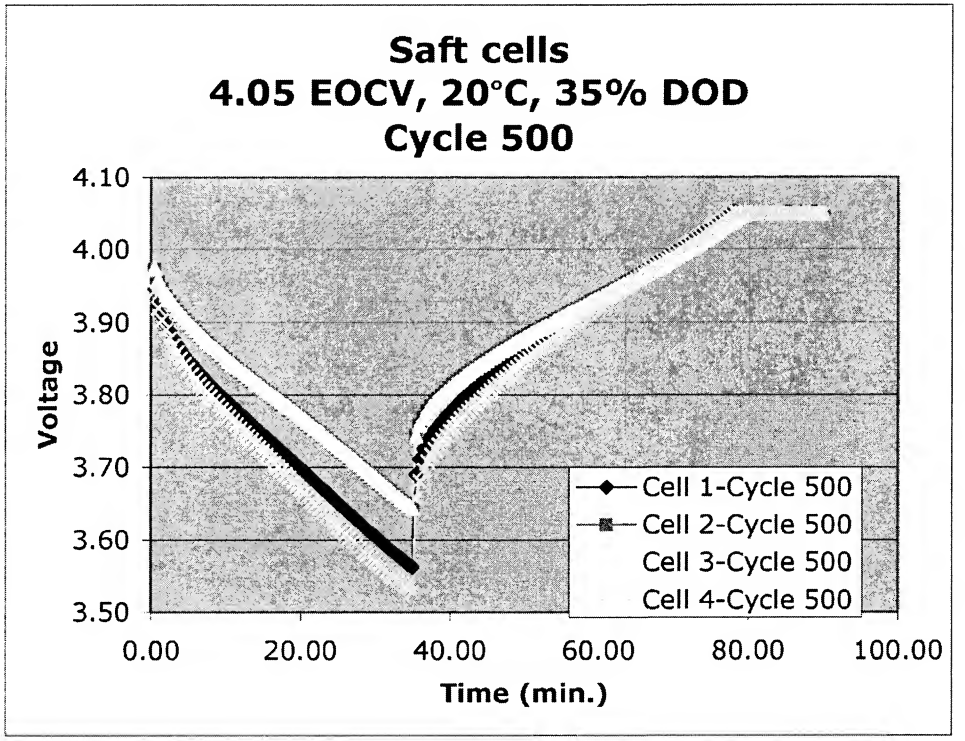
Comparison of full cycle at 10 and 500 Cycles





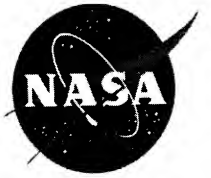
Comparison of full cycle at 10 and 500 Cycles





Lithium-Ion Verification Test Program

- Cell performance stable except for two cells at 4.05 EOCV, 20 degrees C, and 35% DOD
- Details on the charge control will be presented later in the workshop by Concha Reid of GRC and Evan Hand of NSWC/Crane



Acknowledgements

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